Microelectronics Technology Alert

'Microelectronics Technology Alert' tracks significant developments in electronics, optoelectronics, data storage and transfer, focusing on the manufacture of devices using techniques such as vapor deposition and ultralithography. Advances in semiconducting and superconducting materials, capacitors, light emitters and other materials are also monitored. Major changes in industry and novel designs for electronic components and systems are covered.

TECHNICAL INSIGHTS ALERT
Phone: 212-850-8600

MICROELECTRONICS TECHNOLOGY ALERT
NOVEMBER 3, 2000

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FOR ONCE, QUANTUM MECHANICS HELPS CHIPMAKERS

Quantum theory is something chipmakers would like to put off as long as they can. As they continue reducing the size of their etched channels to 25 nm and beyond, quantum theory will kick in and the classical physics they have lived by will no longer set the rules. The good news is that they can't etch features that small now and may not ever get thinner than 180-220 nm, about what they are now.

Curiously, quantum theory could erase that limitation. Quantum physics researchers at NASA's Jet Propulsion Lab and the University of Wales see a way to use quantum mechanics to shrink transistors well beyond current limits. Better news is that they won't have to build entirely new multibillion-dollar fabs to do it.

A major limitation to shrinking chip feature size has been the need to use light of increasingly smaller wavelengths to make exposures. At present, diffraction lets them use their 180 nm to 220 nm ultraviolet light to make transistors as small as 124 nm in width. UV light with very short wavelengths, X-rays, or electron beams can get features smaller, but each will require a new chip lithography system and may be too slow and costly for large-scale manufacturing.

The JPL and Welsh physicists see a way to get smaller wavelengths that can generate much smaller circuitry ("Physical Review Letters" 85: 2733-2736). Photons can, in the quantum world, become entangled, linking their properties and other aspects together, even at a distance.

The researchers suggest hitting crystals made of either potassium diphosphate or potassium triphosphate

with small-wavelength laser light. This will cause the crystals to send out a stream of entangled photons. Aim the entangled photons at two slits. When light is aimed at a diffraction grating, the light passes through the slits and forms characteristic patterns on the other side.

Send an entangled pair of photons through the slits and they appear to have twice the energy of ordinary photons--the entangled pairs pass through both slits simultaneously. The entangled pairs recombine on the far side where they form a wavelength half the size of what can be generated by unentangled photons. A conventional 248 nm laser beam could be reduced to a wavelength of 62 nm to make transistors with features that size, roughly a third as big as current methods can make.

Entangle three or more photons and you can make even smaller circuitry with an ordinary laser and optics. We know how to entangle two photons and have some ideas how to entangle more. But going from theory to production won't be an easy jump.

At present we don't really have good sources for bright entangled photons. You will get about a million entangled photons per second from the crystal method described. But even a simple laser pointer creates a quadrillion--a billion million--photons a second. Much work remains before we have enough entangled photons for practical use and then we must find a practical method for aiming the entangled photons.

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COMPANY WILL LAUNCH NEW FAST ELECTRO-OPTICS

Things are moving fast for the electro-optic technology we told you about this spring (MTA, 4/7/00). A group of University of Washington chemists came up with an electro-optic device that can translate electric signals into optical transmissions at 100 Gbps and can do it with less than one volt. The technology is chemical: The shape of the organic chromophore embedded in a polymeric modulator is changed.

Microvision Inc.--itself founded to commercialize another University of Washington research technology, Virtual Retinal Display, in which images are drawn directly on the viewer's retina--has formed a subsidiary, Lumera Corp., to develop and market the polymer technology. The university will own stock in Lumera and hold a board position. Lumera will pay royalties from the sale of devices and will support advanced photonics research programs at the university under chemistry professor Larry Dalton, one of the inventors of the new technology.

The heart of the technology is sterically modified organic chromophores whose shape has been changed to reduce the attenuation of electric field poling-induced electro-optic activity caused by strong intermolecular electrostatic interactions. Devices using the polymers will be able to translate electrical signals into optical signals at rates up to 100 Gbps. Information processing speeds as much as an order of magnitude faster than current electronic devices will be achieved. And the operating power is a fraction of a volt.

It can lead to modulators directly integrated with the fastest VLSI (very large-scale integration) electronics without using low-noise (and bandwidth-limiting) amplifiers. This would lead us to high-bandwidth opto chips.

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ORGANIC TRANSISTOR ISSUES LASER-LIKE LIGHT

This looks like a very promising architecture for a new kind of electrically driven laser action in organic semiconductors. Researchers at Bell Labs have coaxed a laser-like light from an organic field effect transistor (FET). Organic FETs, cheaper, more flexible, and easier to work with than the more usual silicon variety, are being pushed toward as many electronic applications as they can be made to fit. This would be a new one.

The Bell Labs group is working with ambipolar transistors that can move current as either electrons or holes. They adjust the electron and hole concentrations so that there are equal amounts near the middle of the channel through which the current flows. When they recombine here they emit nearly coherent light, the lockstep laser effect ("Science" 290: 963-965).

Most FETs are unipolar and minority carrier effects are negligible. Ambipolar FETs will work either as n- or p-channel devices depending on the polarity of the gate bias. They can operate in a bipolar mode in which both electron and hole currents are injected into the device at separate electrodes. They aren't new: We've had ambipolar FETs in amorphous silicon, organic semiconductor heterostructures, and organic single crystals. To get good charge transport for both electrons and holes you use a high-quality gate insulator.

The Bell Labs light-emitting ambipolar FET is based on single crystals of the organic semiconductor alpha-sexithiophene (alpha-6T). Electrons are injected from the source electrodes and holes from the drain electrodes and their concentrations are controlled by the applied gate and drain-source voltages. This way you can get equal injection of electron and hole currents to form a pn-junction within the device. The junction generates excitons.

At high excitation levels, you get electrically driven amplified spontaneous photon emission. Threshold currents for stimulated emission are a few tens of microamperes. This is so low that it is a surprise that you are getting coherent light.

Factors favorable for amplified spontaneous emission were built into the device. Balanced electron and hole injection and tight confinement of excitons in two dimensions do it. The device also has good thermal properties. Thermal conductivity of most organic materials is low, making heat dissipation in organic lasers a major problem. But in the Bell Labs device, power dissipation occurs everywhere in the channel while gain is confined to a small part of the channel. This not only helps dissipate power but also plays an important part in the stimulated emission at low threshold.

It was done without expensive lithography or, for that matter, any etching at all of the semiconductor. It is all a matter of device geometry. The device is constructed of single crystals of alpha-6T with aluminum drain and source contacts, a sputtered aluminum oxide gate insulating layer, and an aluminum p-doped zinc oxide gate electrode.

The 20 microamp threshold is comparable to that of the best III-V semiconductor-based vertical cavity surface-emitting lasers, which are much smaller in size. The threshold current density (less than 1 A/sq cm) is the lowest for stimulated emission achieved in any material system at room temperature. The

electrical threshold current density (current/channel cross section) is in the range of kA/sq cm, similar to electrically driven stimulated emission in tetracene. Another unusual feature: The excitons are formed in a region where the electric field is close to zero.

The maximum gain achieved, about 900 cm (exp -1), is about an order of magnitude greater than the system's loss of 100 cm (exp -1). It should be possible to build DBR (distributed Bragg reflector) lasers with organic FETs by incorporating a grating in the structure. It may also be possible to include 2D photonic crystal-based couplers to couple light vertically out of the device.

Pulsed operation should be simple--you only have to apply a voltage pulse to the gate. The device's structure is suitable for integrating emissive devices with control devices to perform switching functions. In such a drive transistor the ohmic contact would be formed with a low work function metal. Since the Schottky barrier for hole injection will operate in a predominantly unipolar n-channel mode, the same three-terminal device can double as switching transistor and laser.

The architecture is compatible with crystalline films of organic semiconductors that can be grown on flexible plastic substrates. You could realize low-cost large-area organic semiconductor lasers. The structure, which requires no intentional doping, could also be useful for getting laser action in material systems that are difficult to dope.

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OPTICAL FLIP-FLOP SWITCH IS FAST AND FLEXIBLE

As soon as anyone realizes that the usual way of switching data over an optical network is to convert the optical signal to electric, make the switch, then turn it back into light again, they are bound to be at least somewhat aghast. Information moves quickly along the optical information superhighway, then hits these speed bumps.

An optical light-to-light switch built by researchers at the University of Rochester with people at University of Tokyo could change this. We have other all-optical switches, but this one is so flexible that it can reformat the information in ways and at speeds that no other device can touch.

It opens and closes in a nanosecond, letting only an exact amount of light through and only light at the right wavelength. It is smaller than a grain of sand, has no moving parts, and is made entirely from off-the-shelf components.

The optical flip-flop switch consists of a laser and a microscale piece of indium phosphide semiconductor. The photonic crystal picks out particular wavelengths of light over a wide range. When a pulse of light at wavelength A comes into the semiconductor from a communications line, the material becomes transparent to the device's laser. The laser, working at wavelength B, shines through briefly before the transparency ends, recreating the original pulse of light in the new wavelength. Thus you have converted the pulse from wavelength A to wavelength B in a nanosecond or less.

Such quick conversion of a pulse's wavelength is important where two fiber-optic networks intersect. One line, say the long-distance trunk line, may use one wavelength and the other, a local phone company, may use a different one. You must make a fast conversion. The exchange between light and electronics usually used to make this conversion is expensive and slow. We have several light-to-light

routing switches, but these do not convert wavelengths.

The Rochester-Tokyo switch also removes another hurdle encountered at the junction of optical networks. Different networks use different lengths of pulses. Since the new optical flip-flop switch works so fast, you can customize the length of the pulses by simply varying the time before the transparency is cut off. Leaving it there a little longer gives you a longer pulse, shutting it sooner makes a shorter pulse.

The two universities have applied for a joint patent on the optical flip-flop switch. Since the parts are all commercially available, the researchers feel that development of the device should be quick. It could play a large role in an optical switching market that is anticipated by "Photonics Spectra" magazine to reach $15 billion in North America and Europe by 2004.

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GLOWING NANOCRYSTAL FILMS MAKE MICROCAVITIES

Semiconductor nanocrystals are all the rage now in photonic labs. The size of the particles determines their optical properties because each size carries a different quantum-confined hole and electron situation. You can tune the absorption or emission of an optoelectronic device by controlling the nanocrystal size.

Physicists at England's Cambridge University have demonstrated that microcavities with semiconductor emitters can be easily fabricated by spin-coating. They incorporated films of core-shell nanocrystals into wavelength-scale, high-Q, planar microcavities. Optically excite them and emission from the nanocrystals couples to the discrete optical modes of the microcavity. At room temperature, the microcavity emission spectrum is independent of excitation intensity for excitation densities up to about one electron-hole pair per nanocrystal ("Applied Physics Letters" 77: 2500-2502).

Their fabrication technique has much to offer over the usual MBE (molecular beam epitaxy)-grown quantum dot microcavities. You get flexible choice of nanocrystal size, composition, and concentration. Plus it is easy.

Their colloidally grown cadmium selenium nanocrystals with epitaxial zinc-sulfur shells show highly efficient, size-tunable luminescence. Adding an epitaxial, wide-bandgap semiconductor shell such as this around the nanocrystalline core confines carriers to the core, reducing trapping at surface states. Such core-shell nanocrystals have shown room-temperature photoluminescence efficiency of 60% to 80% in solution, making them good candidates as high-gain media for lasers or fiber amplifiers.

You can change the emission spectrum of nanocrystals not only by changing the particle size, but also by changing the optical environment. Putting them into planar microcavities significantly changes the distribution of available optical modes so that emission wavelength is determined by cavity dimension. Normally, the microcavities contain quantum dots grown by MBE. The Cambridge group studied microcavities containing size-tunable nanocrystals dispersed in a polymer matrix deposited by spin coating.

In their experiments, nanocrystals with core diameters of about 2.5 nm showed a photoluminescence efficiency of 65%. Poly(isobutylmethacrylate) is the matrix used. The spin-coated film with a nanocrystal concentration of 30% by weight gives a photoluminescence efficiency in the range of 10% to

12%, good for such applications. The polymer/nanocrystal film is about 200 nm thick. A 60 nm silver mirror is thermally evaporated on top of the nanocrystal/polymer film, producing a microcavity resonator with a theoretical maximum Q value of about 150 at wavelengths of 500-600 nm.

They saw significant alteration of the emission spectrum with emission falling into well-defined microcavity modes. There was no evidence of optical gain at excitation densities up to one electron-hole pair per nanocrystal.

The most important thing they demonstrated was that we could combine the advantages of robust semiconductor emitters with the advantages of solution processing. It looks as though we can fabricate structures with two- or three-dimensional optical confinement by lateral patterning of polymer/nanocrystal films.

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